INVENTION: Multiple Data Rate Complex Walsh Codes for CDMA

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TECHNICAL FIELD

The present invention relates to CDMA (Code Division Multiple Access) cellular telephone and wireless data communications with data rates up to multiple T1 (1.544 Mbps) and higher (>100 Mbps), and to optical CDMA with data rates in the Gbps and higher ranges. Applications are mobile, point-to-point and satellite communication networks. More specifically the present invention relates to novel multiple data rate algorithms for complex and hybrid complex Walsh orthogonal CDMA codes. These algorithms generate multiple code length complex Walsh and hybrid complex Walsh orthogonal codes for use as the channelization codes for multiple data rate users. These new algorithms and codes offer substantial improvements over the current real Walsh orthogonal variable spreading factor (OVSF) CDMA codes for the next generation wideband CDMA (W-CDMA).

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ABSTRACT

The present invention describes new multiple data rate algorithms for complex Walsh and hybrid complex Walsh orthogonal CDMA channelization encoding and decoding of multiple data rate users. Complex Walsh and hybrid complex Walsh orthogonal CDMA

codes have been disclosed in a previous patent application [6] for constant data rate communications. These algorithms generate a means to accomodate multiple data rate users over the same CDMA frequency band using complex Walsh and hybrid complex Walsh orthogonal codes.

The means of this invention is to provide complex Walsh and hybrid complex Walsh with the means to separate the different data rate users in the sequency domain of the complex Walsh analogous to the current use of different frequency bands for the different data rate users. Sequency for complex Walsh and hybrid complex Walsh codes is the average rate of phase angle rotations of the code vectors, and is analogus to frequency in the Fourier domain. For example, a frequency equal to 1 rotation per N chip code length corresponds to a sequency equal to 1 complete phase rotation over the N chip code vector length. However, for real Walsh codes the definition of sequency is the average number of sign changes of the code vectors, and has no direct analogy to frequency. The widest sequency bands consisting of sets of N/2 contiguous sequencies is reserved for the highest data rate users who transmit at a 2 chip code rate, the next widest sequency bands consisting of N/4 contiguous sequencies is reserved for the 4 chip code rate users,...., and the narrowest sequeny bands consisting of a single sequency are reserved for the N chip code rate users.

Current art uses algorithms to generate multiple code length real Walsh CDMA orthogonal codes for the next generation wideband CDMA (W-CDMA). These codes are orthogonal variable spreading factor (OVSF) CDMA codes. Spreading factor is the length of each code, and a variable spreading factors refers to a variable code length or equivalently to a choice of multiple code lengths.

The present invention provides a means to significantly improve CDMA performance for multiple data rate users by allowing the use of the new complex Walsh and hybrid complex Walsh CDMA

orthogonal codes in place of the real Walsh OVSF CDMA orthogonal codes and with implementation means for fast and computationally efficient encoding and decoding. Fundamental improvements are known to include an increase in the carrier-to-noise ratio (CNR) for data symbol recovery in the receiver, lower correlation side-lobes under timing offsets both with and without PN spreading, lower levels of harmonic interference caused by non-linear amplification of multi-carrier CDMA signals, and reduced phase tracking jitter for code tracking to support both acquisition and synchronization. Hybrid complex Walsh orthogonal CDMA codes increase the choices for the code lengths by allowing the combined use of complex Walsh, Hadamard, and discrete Fourier transform complex orthogonal codes using a Kronecker construction, direct sum construction, as well as the possibility for more general functional combining.

BACKGROUND ART

Current art is represented by the work on orthogonal spreading factor (OVSF) real Walsh codes for wideband CDMA (W-CDMA) for the third generation CDMA (G3) proposed standard candidates and for broadband wireless communications, and the previous work on the real Walsh fast transform algorithms. These are documented in references 1,2,3,4,5. Reference 1 is an issue of the IEEE communications journal devoted to wideband CDMA including OVSF. References 2 and 3 are issues of the IEEE communications magazine that are devoted to "Multiple Access for Broadband Networks" and "Wideband CDMA". Reference 4 is an issue of the IEEE personal communications devoted to "Third Generation Mobile Systems in Europe". Reference 5 is the widely used reference on real Walsh technology which includes algorithms for the fast Walsh transform. The new complex Walsh and hybrid complex Walsh orthogonal CDMA codes being addressed in this invention for application to multiple data rate users, have been disclosed in a previous patent application [6] for constant data rate communications.

Current art using real Walsh orthogonal CDMA channelization codes to generate OVSF codes for multiple data rate users is represented by the scenario described in the following with the aid of equations (1) and (2) and FIG. 1,2,3,4. This scenario considers CDMA communications spread over a common frequency band for each of the communication channels. These CDMA communications channels for each of the multiple rate users are defined by assigning a unique real Walsh orthogonal spreading code to each user. This real Walsh code has a maximum length of N chips with $N=2^M$ where M is an integer, with shorter lengths of 2,4,…,N/2 for the higher data rate users. These multiple length real Walsh codes have limited orthogonality properties and occupy the same frequency band. These Walsh encoded user signals are summed and then re-spread over the same frequency band by PN codes, to generate the CDMA communications signal which is modulated and transmitted. The communications link consists of a transmitter, propagation path, and receiver, as well as interfaces and control.

It is assumed that the communication link is in the communications mode with the users communicating at symbol rates equal to the code repetition rates of their respective communications channels and that the synchronization is sufficiently accurate and robust to support this communications mode. In addition, the power differences between users due to differences in data rates and in communication link budget parameters is assumed to be incorporated in the data symbol amplitudes prior to the CDMA encoding in the CDMA transmitter, and the power is uniformly spread over the wideband by proper selection of the CDMA pulse waveform. It is self evident to anyone skilled in the CDMA communications art that these communications mode assumptions are both reasonable and representative of the current CDMA art and do not limit the applicability of this invention.

Transmitter equations (1) describe a representative real Walsh CDMA encoding for multiple data rate users for the

transmitter in FIG. 1. These equations represent a considerably more sophisticated and improved implementation of current OVSF CDMA communications which has been developed to help support the new invention for complex Walsh and hybrid complex Walsh CDMA orthogonal codes.

Lowest data rate users are assumed to communicate at the lowest symbol rate equal to the code repetition rate of the N chip real Walsh code, which means they are assigned N chip code vectors from the NxN real Walsh code matrix W_N in **1** for their channelization codes. Higher data rate users will use shorter real Walsh codes. The reference real Walsh code matrix W_N has N Walsh row code vectors $W_N(c)$ each of length N chips and indexed by $c=0,1,\ldots,N-1$, with $W_N(c)=[W_N(c,1),\ldots,W_N(c,N)]$ wherein $W_N(c,n)$ is chip n of code u. Walsh code chip n of code vector u has the possible values $W_N(c,n)= +/-1$.

Multiple data rate menu in **2** lists the possible user data symbol rates R_s and the corresponding code lengths and symbols transmitted over each N chip reference code length. User symbol rate $R_s=1/NT$ is the code repetition rate 1/NT of the N chip code over the code time interval NT. User data rate R_b in bits/second is equal to $R_b=R_sb_s$ where b_s is the number of data bits encoded in each data symbol. Assuming a constant b_s for all of the multiple data rate users, the user data rate becomes directly proportional to the user symbol rate $R_b\sim R_s$ which means the user symbol rate menu in **1** is equivalent to the user data rate menu.

User data symbols and channelization codes are listed in **3** for the multiple rate users. Users are grouped into the data rate categories corresponding to their respective code chip lengths $2,4,8,\ldots,N/2,N$ chips. User groups are indexed by $m=1,2,\ldots,M$ where group m consists of all users with $N(m)=2^m$ chip length codes drawn from the N(m)xN(m) real Walsh code matrix $W_{N(m)}$. Users within group m are identified by the index u_m which is set equal to the Walsh channelization code vector index in $W_{N(m)}$. Code chip n_m of the user code u_m is equal to $W_{N(m)}(u_m, n_m)$

where $n_m=0,1,2,\ldots,N(m)-1$ is the chip index. User data symbols $Z(u_{m,k_m})$ are indexed by u_{m,k_m} where the index $k_m=0,1,2,\ldots,N/N(m)-1$ identifies the data symbols of u_m which are transmitted over the N chip code block. The total number of user data symbols transmitted per N chip block is N which means the number of channel assignments $\{u_m,\ m=1,2,\ldots,M\}$ will be less than N for multiple data rate CDMA communications when there is at least one user using a higher data rate.

Current multiple data rate real Walsh CDMA encoding for transmitter **(1)**

1 N chip Walsh code block

W_N = Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [$W_N(c)$] matrix of row vectors $W_N(c)$

= [$W_N(c,n)$] matrix of elements $W_N(c,n)$

$W_N(c)$ = Walsh code vector c for $c=0,1,\ldots,N-1$

= [$W_N(c,0),\ W_N(c,1),\ \ldots,\ W_N(c,N-1)$]

= 1xN row vector of chips $W_N(c,0),\ldots,W_N(c,N-1)$

$W_N(c,n)$ = Walsh code c chip n

= +/+1 possible values

2 Multiple data rate menu

N chip real Walsh symbol rate

R_s = User symbol rate, symbols/second

= 1/NT where T = Chip repetition interval

Symbol rate menu for multiple data rates

		Symbol rate, Symbols/second	Code length, chips	Symbols per N chips
R_s	=	1/2T	2	N/2
	=	1/4T	4	N/4
	=	1/8T	8	N/8
		⋮	⋮	⋮
	=	1/2NT	N/2	2
	=	1/NT	N	1

3 User data symbols and channelization codes

Users are categorized into M groups according to the number of code chips.

m = Index of the user groups
= 1,2,....,M

u_m = One of up to $N(m)=2^m$ possible users in group m

$N(m)$ = Number of code chips for the codes in the user group m
= 2^{m+1}

User data symbols

$Z(u_{m,k_m})$ = User u_m data symbol k_m

k_m = Index for the user data symbols over the N chip code block, for a user from group m
= 0,1,2,...., $N/N(m)-1$

User channelization codes within each group are selected from a subset of the orthogonal codes in the Walsh code matrix.

$W_{N(m)}(u_m)$ = Walsh $1\text{x}2^m$ dimensional code vector u_m in the $N(m)\text{x}N(m)$ Walsh code matrix, for user u_m in the group m

$W_{N(m)}(u_m,n_m)$ = User u_m code chip $n_m=0,1,2,\ldots,N(m)-1$

4 Real Walsh encoding and channel combining

$\tilde{Z}(n)$ = Real Walsh CDMA encoded chip n

$$= \sum_{m=1}^{M} \sum_{u_m} Z(u_{m,k})\ W_{N(m)}(u_m,\ n=n_m+k_m N(m))$$

5 PN scrambling

$P_R(n)$, $P_I(n)$ = PN code chip n for real, imaginary axes axes

$Z(n)$ = PN scrambled real Walsh encoded data chips after summing over the users

$$= \sum_u \widetilde{Z}(n)\,[P_R(n) + j\,P_I(n)]$$

$$= \sum_u \widetilde{Z}(n)\,[\mathrm{sgn}\{P_R(n)\} + j\,\mathrm{sgn}\{P_I(n)\}]$$

= Real Walsh CDMA encoded complex chips after PN scrambling

Walsh encoding and channel combining in **4** encodes each of the users $\{u_m\}$ and their data symbols $\{Z(u_{m,k_m})\}$ with a Walsh code $W_{N(m)}(u_m)$ drawn from the group m of the N(m) chip channelization codes where u_m is the user code. A time delay of $k_m N(m)$ chips before start of the real Walsh encoding of the data symbol k_m in each of the user channels, is required for implementation of the multiple data rate user real Walsh encoding and for the summation of the encoded data chips over the users. Output of this multiple data rate real Walsh encoding and summation over the multiple data rate users is the set of real Walsh CDMA encoded chips $\{\widetilde{Z}(n)\}$ over the N chip block.

PN scrambling of the real Walsh CDMA encoded chips in **5** is accomplished by encoding the $\{\widetilde{Z}(n)\}$ with a complex PN which is constructed as the complex code sequence $[P_R(n)+jP_I(n)]$ wherein $P_R(n)$ and $P_I(n)$ are independent PN sequences used for the real and imaginary axes of the complex PN. These PN codes are 2-phase with each chip equal to +/-1 which means PN encoding consists of sign changes with each sign change corresponding to the sign of the PN chip. Encoding with PN means each chip of the summed Walsh encoded data symbols has a sign change when the corresponding PN chip is -1, and remains unchanged for +1 values. This operation is described by a multiplication of each chip of the summed Walsh encoded data symbols with the sign of

the PN chip. Purpose of the PN encoding for complex data symbols is to provide scrambling of the summed Walsh encoded data symbols as well as isolation between groups of users. Output of this real Walsh CDMA encoding followed by the complex PN scrambling are the CDMA encoded chips over the N chip block $\{Z(n)\}$.

Receiver equations (2) describe a representative multiple data rate real Walsh CDMA decoding for the receiver in FIG. 3. The receiver front end **5** provides estimates $\{\hat{Z}(n)\}$ of the transmitted real Walsh CDMA encoded chips $\{Z(n)\}$. Orthogonality property **6** is expressed as a matrix product of the real Walsh code chips or equivalently as a matrix product of the Walsh code chip numerical signs, for any of the 2,4,8,…,N/2,N chip real Walsh channelization codes and their repetitions over the N chip code block. These codes are orthogonal with respect to the user codes within a group. They are also orthogonal between code groups for the allowable subsets of code assignments to the users, for all code repetitions over the N chip code block. This means that the allowable codes $\{u_m\}$ in group m are orthogonal to the allowable codes $\{u_{m+p}\}$ in group m+p for all code repetitions of the codes $\{u_m\}$ over the N chip code block, for $p \geq 0$.

The 2-phase PN codes **7** have the useful decoding property that the square of each code chip is unity which is equivalent to observing that the square of each code chip numerical sign is unity. Decoding algorithms **8** perform the inverse of the signal processing for the encoding in equations (1) to recover estimates $\{\hat{Z}(u_{m,k_m})\}$ of the transmitter user symbols $\{Z(u_{m,k_m})\}$.

Current multiple data rate real Walsh CDMA decoding for receiver **(2)**

5 Receiver front end provides estimates $\{\hat{Z}(n) = \hat{R}(n) + j\hat{I}(n)\}$ of the encoded transmitter chip symbols $\{Z(n)\}$

6 Orthogonality properties of the set of real Walsh {2x2, 4x4, 8x8, …NxN} matrices

The N(m)xN(m) Walsh code matrices for all m are orthogonal

$$N(m)^{-1}\sum_{n_m} W_{N(m)}(\hat{c}_m, n_m)\, W_{N(m)}(n_m, c_m) \;=\; \delta(\hat{c}_m, c_m)$$

where $c_m, n_m = 0, 1, \ldots, N(m)$

$\delta(\hat{c}_m, c_m)$ = Delta function of $\hat{c}_m$ and c_m

= 1,0 for $\hat{c}_m = c_m$, otherwise

The N(m)xN(m) and N(m+p)xN(m+p) Walsh code matrices for all m and p≥0 are orthogonal for a subset of codes $\{u_m\}$ and $\{u_{m+p}\}$

$$N(m)^{-1}\sum_{n_m} W_{N(m)}(u_m, n_m) \bullet W_{N(m+p)}(u_{m+p},\; n_{m+p} = n_m + k_m N(m))$$

$= 0$ for $k_m = 0, 1, 2\ldots, N/N(m)-1$

7 PN decoding property

$P(n)P(n) = \mathrm{sgn}\{P(n)\ \mathrm{sgn}\{P(n)\}$

$= 1$

8 Decoding algorithm

$$\hat{Z}(u_{m,k_m}) =$$

$$N^{-1}\sum_{n_m} \hat{Z}(n)\ [\mathrm{sgn}\{P_R(n)\} - j\,\mathrm{sgn}\{P_I(n)\}] \bullet$$

$$\mathrm{sgn}\{W_{N(m)}(\ n = n_m + k_m N(m),\ u_m\ )\}$$

= Receiver estimate of the transmitted complex data symbol $Z(u_{m,k_m})$

FIG. 1 CDMA transmitter block diagram is representative of a current CDMA transmitter which includes an implementation of the current multiple data rate real Walsh CDMA channelization encoding in equations (1). This block diagram becomes a representative implementation of the CDMA transmitter which implements the new multiple data rate complex Walsh and hybrid complex Walsh CDMA encoding, when the current multiple data rate real Walsh CDMA encoding **13** is replaced by the new

multiple data rate complex Walsh and hybrid complex Walsh CDMA encoding of this invention.

Signal processing starts with the stream of user input data words **9**. Frame processor **10** accepts these data words and performs the encoding and frame formatting, and passes the outputs to the symbol encoder **11** which encodes the frame symbols into amplitude and phase coded symbols $\{Z(u_{m,k})\}$ **12.** These symbols **12** are the inputs to the current multiple data rate real Walsh CDMA encoding in equations (1). Inputs $\{Z(u_{m,k})\}$ **12** are real Walsh encoded, summed over the users, and scrambled by complex PN in the current multiple date rate real Walsh CDMA encoder **13** to generate the complex output chips $\{Z(n)\}$ **14.** This encoding **13** is a representative implementation of equations (1). These output chips $Z(n)$ are waveform modulated **15** to generate the analog complex signal $z(t)$ which is single sideband upconverted, amplified, and transmitted (Tx) by the analog front end of the transmitter **15** as the real waveform $v(t)$ **16** at the carrier frequency f_0 whose amplitude is the real part of the complex envelope of the baseband waveform $z(t)$ multiplied by the carrier frequency and the phase angle ϕ accounts for the phase change from the baseband signal to the transmitted signal.

It should be obvious to anyone skilled in the communications art that this example implementation in FIG. 1 clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. 2 multiple data rate real Walsh CDMA encoding is a representative implementation of the multiple data rate real Walsh CDMA encoding **13** in FIG. 1 and in equations (1). Inputs are the complex user data symbols $\{Z(u)\}$ **17.** Encoding of each user by the corresponding Walsh code is described in **18** by the implementation of transferring the sign of each Walsh code chip to the user data symbol followed by a 1-to-N expander $1\uparrow N$ of each

data symbol into an N chip sequence using the sign transfer of the Walsh chips. The sign-expander operation **18** generates the N-chip sequence $Z(u_{m,k_m})\,\mathrm{sgn}\{W(u_m, (n=n_m+k_mN(m))\}$ for $n=0,1,\ldots,N-1$ for each user $\{u_m\}$. This Walsh encoding serves to spread each user data symbol into an orthogonally encoded chip sequence which is spread over the CDMA communications frequency band. The Walsh encoded chip sequences for each of the user data symbols are summed over the users **19** followed by PN encoding with the scrambling sequence $[P_R(n)+jP_I(n)]$ **20.** PN encoding is implemented by transferring the sign of each PN chip to the summed chip of the Walsh encoded data symbols. Output is the stream of complex multiple data rate real Walsh CDMA encoded chips $\{Z(n)\}$ **21.**

It should be obvious to anyone skilled in the communications art that this example implementation in FIG. 2 clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. 3 CDMA receiver block diagram is representative of a current CDMA receiver which includes an implementation of the current multiple data rate real Walsh CDMA decoding in equations (2). This block diagram becomes a representative implementation of the CDMA receiver which implements the new multiple data rate complex Walsh and hybrid complex Walsh CDMA decoding when the current multiple data rate real Walsh CDMA decoding **27** is replaced by the new multiple data rate complex Walsh and hybrid complex Walsh CDMA decoding of this invention.

FIG. 3 signal processing starts with the user transmitted wavefronts incident at the receiver antenna **22** for the users $\{u_m\}$. These wavefronts are combined by addition in the antenna to form the receive (Rx) signal $\hat{v}(t)$ at the antenna output **22** where $\hat{v}(t)$ is an estimate of the transmitted signal v(t) **16** in FIG. 1, that is received with errors in time Δt, frequency Δf,

phase $\Delta\theta$, and with an estimate $\hat{z}(t)$ of the transmitted complex baseband signal z(t) **16** in FIG. 1. This received signal $\hat{v}(t)$ is amplified and downconverted by the analog front end **23** and then synchronized and analog-to-digital (ADC) converted **24.** Outputs from the ADC are filtered and chip detected **25** by the fullband chip detector, to recover estimates $\{\hat{Z}(n)\}$ **26** of the transmitted signal which is the stream of complex CDMA encoded chips {Z(n) **14** in FIG. 1. CDMA decoder **27** implements the algorithms in equations (2) by stripping off the PN code(s) and decoding the received CDMA real Walsh orthogonally encoded chips to recover estimates $\{\hat{Z}(u_{m,k_m})\}$ **28** of the transmitted user data symbols $\{Z(u_{m,k_m})\}$ **12** in FIG. 1. These estimates **28** are processed by the symbol decoder **29** and the frame processor **30** to recover estimates **31** of the transmitted user data words.

It should be obvious to anyone skilled in the communications art that this example implementation clearly defines the fundamental current CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. 4 multiple data rate real Walsh CDMA decoding is a representative implementation of the multiple data rate real Walsh CDMA decoding **27** in FIG. 3 and in equations (2). Inputs are the received estimates of the multiple data rate comple real Walsh CDMA encoded chips $\{\hat{Z}(n)\}$ **32.** The PN scrambling code is stripped off from these chips **33** by changing the sign of each chip according to the numerical sign of the real and imaginary components of the complex conjugate of the PN code as per the decoding algorithms **8** in equations (2). Real Walsh channelization coding is removed in **34** by a pulse compression operation consisting of multiplying each received chip by the numerical sign of the corresponding Walsh chip for the user and

summing the products over the N Walsh chips to recover estimates $\{\hat{Z}(u_{m,k_m})\}$ **35** of the user complex data symbols $\{Z(u_{m,k_m})\}$.

It should be obvious to anyone skilled in the communications art that this example implementation clearly defines the fundamental current CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

For cellular applications the transmitter description describes the transmission signal processing applicable to this invention for both the hub and user terminals, and the receiver describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.

For optical communications applications the the microwave processing at the front end of both the transmitter and the receiver is replaced by the optical processing which performs the complex modulation for the optical laser transmission in the transmitter and which performs the optical laser receiving function of the microwave processing to recover the complex baseband received signal.

SUMMARY OF INVENTION

This invention is a new set of fast and computationally efficient algorithms for new multiple data rate orthogonal channelization encoding and decoding for CDMA using the new complex Walsh codes and the hybrid complex Walsh orthogonal codes in place of the current real Walsh orthogonal codes. Real Walsh codes are used for current CDMA applications and will be used for all of the future CDMA systems. The newly invented complex Walsh codes disclosed in [6] provide the choice of using the new complex Walsh codes or the real Walsh codes since the real Walsh codes are the real components of the complex Walsh codes. This means an application capable of using the complex Walsh codes can

simply turn-off the complex axis components of the complex Walsh codes for real Walsh CDMA coding and decoding.

Performance is improved for the multiple data rate CDMA communications when the new 4-phase complex Walsh orthogonal CDMA codes replace the current 2-phase real Walsh codes. These improvements include an increase in the carrier-to-noise ratio (CNR) for data symbol recovery in the receiver, lower correlation side-lobes under timing offsets both with and without PN spreading, lower levels of harmonic interference caused by non-linear amplification of multi-carrier CDMA signals, and reduced phase tracking jitter for code tracking to support both acquisition and synchronization. These potential performace improvements simply reflect the widely known principle that complex CDMA is better than real CDMA.

In addition to the performance improvement, there are greater code length choices for multiple data rate CDMA communications using the new hybrid complex Walsh orthogonal CDMA codes in place of the complex Walsh orthogonal CDMA codes which have been disclosed in [6]. Code length choices are increased by the combined use of complex Walsh and discrete Fourier transform complex orthogonal codes using a Kronecker construction, direct sum constructioin, as well as the possibility for more general functional combining.

BRIEF DESCRIPTION OF DRAWINGS

The above-mentioned and other features, objects, design algorithms, and performance advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings and performance data wherein like reference characters and numerals denote like elements, and in which:

FIG. 1 is a representative CDMA transmitter signal processing implementation block diagram with emphasis on the current multiple data rate real Walsh CDMA encoding which

contains the signal processing elements addressed by this invention disclosure.

FIG. 2 is a representative real Walsh CDMA encoding implementation diagram with emphasis on the current multiple data rate real Walsh CDMA encoding which contains the signal processing elements addressed by this invention disclosure.

FIG. 3 is a representative CDMA receiver signal processing implementation block diagram with emphasis on the current multiple data rate real Walsh CDMA decoding which contains the signal processing elements addressed by this invention disclosure.

FIG. 4 is a representative CDMA decoding implementation diagram with emphasis on the current multiple data rate real Walsh CDMA decoding which contains the signal processing elements addressed by this invention disclosure.

FIG. 5 is a representative CDMA encoding implementation diagram which describes the new complex Walsh and hybrid complex Walsh CDMA encoding of multiple data rate users and which contains the signal processing elements addressed by this invention disclosure.

FIG. 6 is a representative CDMA decoding implementation diagram which describes the new complex Walsh and hybrid complex Walsh CDMA decoding of multiple data rate users and which contains the signal processing elements addressed by this invention disclosure.

DISCLOSURE OF INVENTION

The new invention provides the algorithms and implementation architectures to support simultaneous multiple data rates or equivalently simultaneous multiple symbol rates using the new complex Walsh and hybrid complex Walsh orthogonal CDMA codes which have been disclosed in the invention application [6]. Simultaneous multiple data rates over the same CDMA frequency spectrum are well known in CDMA networking and been included in the next generation UMTS 3G evolving CDMA using

wideband CDMA (W-CDMA) and real Walsh orthogonal CDMA channeliztion codes.

The current art uses three categories of techniques designed to accommodate multiple data rate users and these are A) multiple chip length codes for the multiple data rate users, B) same chip length codes with the number of codes adjusted as required for the multiple data rate users, and C) different frequency spectrums assigned to the multiple data rate users which is frequency division multiplexing (FDM). The first technique is the preferred choice for W-CDMA primarily because of the de-multiplexing and multiplexing required for the second technique and because of the configurable multi-rate filters required for the spectrum partitioning in the third approach. This new invention implements the second and third approaches without their disadvantages and moreover provides the added performance improvements that will be realized with the use of the complex Walsh and hybrid complex Walsh codes in place of the real Walsh codes. These new 4-phase complex Walsh orthogonal CDMA codes replacing the current 2-phase real Walsh codes will provide improvements that include an increase in the carrier-to-noise ratio (CNR) for data symbol recovery in the receiver, lower correlation side-lobes under timing offsets both with and without PN spreading, lower levels of harmonic interference caused by non-linear amplification of multi-carrier CDMA signals, and reduced phase tracking jitter for code tracking to support both acquisition and synchronization. These potential performace improvements simply reflect the widely known principle that complex CDMA is better than real CDMA. The hybrid complex Walsh offers these same improvements together with the flexibility of more choices in the code lengths at the expense of increasing the number of code phases on the unit circle thereby introducing multiplications into the encoding and decoding implementations.

The new complex Walsh and hybrid complex Walsh CDMA orthogonal codes disclosed in [6] have been invented to be the

natural development for the Walsh codes and therefore are the correct complex Walsh codes to within arbitrary factors that include scale and rotation, which are not relevant to performance. This natural development of the complex Walsh codes in the N-dimensional complex code space C^N extended the correspondences between the real Walsh codes and the Fourier codes in the N-dimensional real code space R^N, to correspondences between the complex Walsh codes and the discrete Fourier transform (DFT) codes in C^N.

The new hybrid complex Walsh orthogonal CDMA codes increase the choices for the code length by allowing the combined use of complex Walsh and discrete Fourier transform complex orthogonal codes using a Kronecker construction, direct sum constructioin, as well as the possibility for more general functional combining.

Transmitter equations (3) describe a representative complex Walsh CDMA encoding for multiple data rate users for the transmitter in FIG. 1 using the definition of the complex Walsh CDMA codes in the invention application [6]. Lowest data rate users are assumed to communicate at the lowest symbol rate equal to the code repetition rate of the N chip complex Walsh code, which means they are assigned N chip code vectors from the NxN complex Walsh code matrix $\widetilde{W}_N$ in **36** for their channelization codes. Higher data rate users will use shorter complex Walsh codes. Reference complex Walsh code matrix $\widetilde{W}_N$ has N Walsh row code vectors $\widetilde{W}_N(c)$ each of length N chips and indexed by c=0,1,…,N-1, with $\widetilde{W}_N(c)=[\widetilde{W}_N(c,0),\ldots,\ \widetilde{W}_N(c,N-1)]$ wherein $\widetilde{W}_N(c,n)$ is chip n of code c with the possible values $\widetilde{W}_N(c,n)= +/-1\ +/-j$. Complex Walsh code vectors in the N dimensional complex code space C^N are defined using the real Walsh code vectors from the N dimensional real code space R^N for the real and complex code vectors using the equation $\widetilde{W}_N(c)=W(cr)+jW(ci)$ where the mapping of the complex Walsh code index c into the real Walsh code

indices cr and ci is defined by the mapping of c into cr(c) and ci(c) in **36.**

The multiple data rate menu in **37** lists the possible user data symbol rates R_s and the number of symbols transmitted over each N chip reference code length. User symbol rate $R_s=1/N(m)T$ for the users in group m is equal to the number of user data symbols N/N(m) over the N chip code block multiplied by the symbol rate rate 1/NT of the N chip code. User data rate R_b in bits/second is equal to $R_b=R_sb_s$ where b_s is the number of data bits encoded in each data symbol. Assuming a constant b_s for all of the multiple data rate users, the user data rate becomes directly proportional to the user symbol rate $R_b \sim R_s$ which means the user symbol rate menu in **37** is equivalent to the user data rate menu.

Data symbol vector **38** stores the N data symbols $\{Z(u_{m,k_m})\}$ for the N chip code block in an 1xN dimensional data symbol vector indexed by $d=d_0+d_1 2+d_2 4+\ldots+d_{M-2}N/4+d_{M-1}N/2 =0,1,2,\ldots,N-1$, where the binary word represention is $d=d_0\cdots d_{M-1}$ and the $\{d_m\}$ are the binary coefficients. With the availability of this 1xN dimensional data symbol vector, it is observed that the real Walsh implementation for the multiple data rate users in **3** in equations (3) must assign the 2 chip data symbols $Z(u_0,z_k)$ to the d_{M-1} field, the 4 chip data symbols $Z(u_1, z_k)$ to the $d_{M-1}d_{M-2}$ field, …., and the N chip data symbols $Z(u_{M-1}, z_k)$ to the $d_0\cdots d_{M-1}$ field in order to provide orthogonality between the code vectors in the different groups. For the complex Walsh the same data assignment is used with the modification that the N/N(m) data symbols for the N(m) chip code vectors of group m assigned to data field $d_{M-m}d_{M-m+1}\bullet\bullet\bullet\bullet d_{M-1}$ of d using the real Walsh, are now mapped into N/N(m) N-chip code vectors over the same group m data field $d_{M-m}d_{M-m+1}\bullet\bullet\bullet\bullet d_{M-1}$ of d. This allows a fast algorithm to be used and uses the N chip codes over the $d_{M-m}d_{M-m+1}\bullet\bullet\bullet\bullet d_{M-1}$ field of d which field occupies the same sequency band as the frequency band

for FDM. This removes the disadvantages of using technique "B" and "C" for W-CDMA, and helps to make the complex Walsh the preferred choice compared to technique "A" which is the current art preferred choice with real Walsh.

The new invention has found a means to use the same data fields of the current W-CDMA for real Walsh, for application to the complex Walsh with the added advantages of a fast transform, simultaneous transmission of the user data symbols, and the assignment of these user data symbols to a contiguous sequency band specified by the data field of d for additional isolation between users. For a fully loaded CDMA communications frequency band the N data symbols for the multiple rate users occupy the N available data symbol locations in the data symbol vector d= $d_0 \cdots d_{M-1}$. The construction of the data symbol vector is part of this invention disclosure and provides a means for the implementation of a fast complex Walsh encoding and decoding of the multiple data rate complex Walsh CDMA. Examples 1 and 2 in **39** and **40** illustrate representative user assignments to the data fields of the data symbol vector. This mapping of the user data symbols into the data symbol vector is equivalent to setting c=d which makes it possible to develop the fast encoding algorithm **41**.

New multiple data rate complex Walsh encoding for transmitter **(3)**

36 N chip complex Walsh code block

$\widetilde{W}_N$ = complex Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [$\widetilde{W}_N(c)$] matrix of row vectors $\widetilde{W}_N(c)$

= [$\widetilde{W}_N(c,n)$] matrix of elements $\hat{W}_N(c,n)$

$\widetilde{W}_N(c)$ = complex Walsh code vector c

= $W_N(cr) + jW_N(ci)$ for c=0,1,…,N-1

$W_N(cr)$, $W_N(ci)$ = Real Walsh 1xN code vectors cr,ci

c = 0,1,2,…,N-1

= Real Walsh code index for N chip block

= (cr,ci) Pair of real Walsh code vectors cr=cr(c) and ci=ci(c) which are assigned to the real and to the imaginary axes

n = 0,1,2,…,N-1

= Chip index for N chip block

Mapping of real Walsh to complex Walsh

Complex Walsh code c	Real Axis real Walsh codes cr(c)	Complex Axis real Walsh codes ci(c)
0	0	0
1,2,…,N/2-1	2c	2c-1
N/2	N-1	N-1
N/2+1,…,N-1	2N-2c-1	2N-2c

$\tilde{W}$(c,n) = complex Walsh code u chip n

= +/-1 +/-j possible values

$$= (-1)\char`^ \, [cr_{M-1}n_0 + \sum_{i=1}^{i=M-1}(cr_{M-1-i} + cr_{M-i})n_i\,]$$

$$+ j(-1)\char`^ \, [ci_{M-1}n_0 + \sum_{i=1}^{i=M-1}(ci_{M-1-i} + ci_{M-i})n_i\,]$$

cr = $\sum_{i=0}^{i=M-1} cr_i 2^i$ binary representation of cr

ci = $\sum_{i=0}^{i=M-1} ci_i 2^i$ binary representation of ci

n = $\sum_{i=0}^{i=M-1} n_i 2^i$ binary representation of n

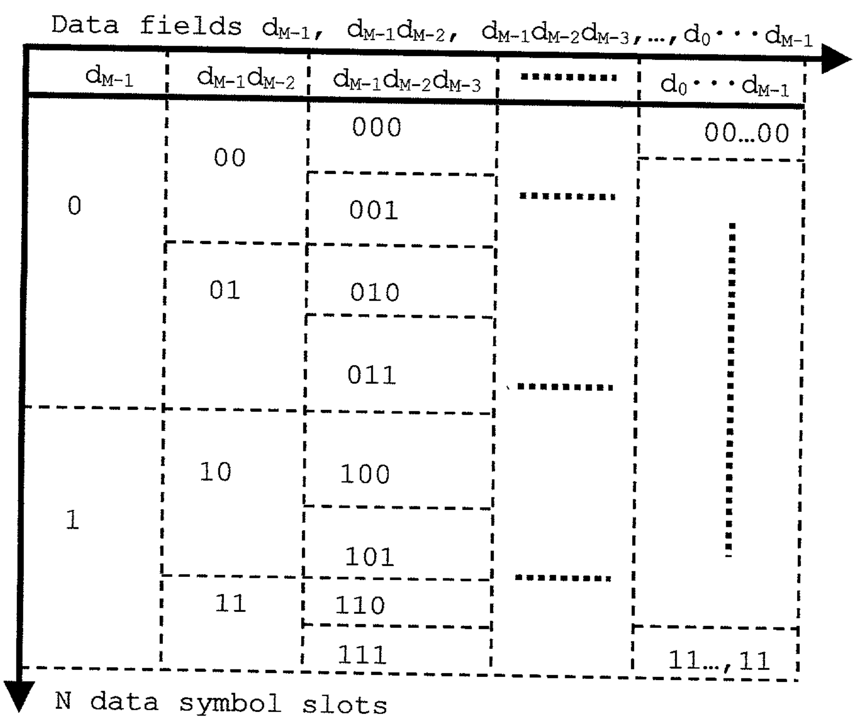
= $W_N(cr) + jW_N(ci)$ for $c_m=0,1,\ldots,2^m-1$

37 Multiple data rate menu

Symbol rate menu for multiple data rates

Symbol rate		Symbol rate, Symbols/second	Symbols per N chips
R_s	=	1/2T	N/2
	=	1/4T	N/4
	=	1/8T	N/8
		⋮	⋮
	=	1/2NT	2
	=	1/NT	1

38 Data symbol vector field indexed by $d=d_0+d_1 2+d_2 4+\ldots+d_{M-2} N/4+d_{M-1} N/2$ is partitioned into M data fields with each assigned to one group of multiple data rate users. Writing d as a binary word $d=d_0 d_1 \cdots d_{M-1}$ enables the data fields to be identified as d_{M-1}, $d_{M-1}d_{M-2}$, $d_{M-1}d_{M-2}d_{M-3}$, …, $d_0 \cdots d_{M-1}$ which respectively are assigned to the user groups u_0, u_1, …, u_{M-1}.



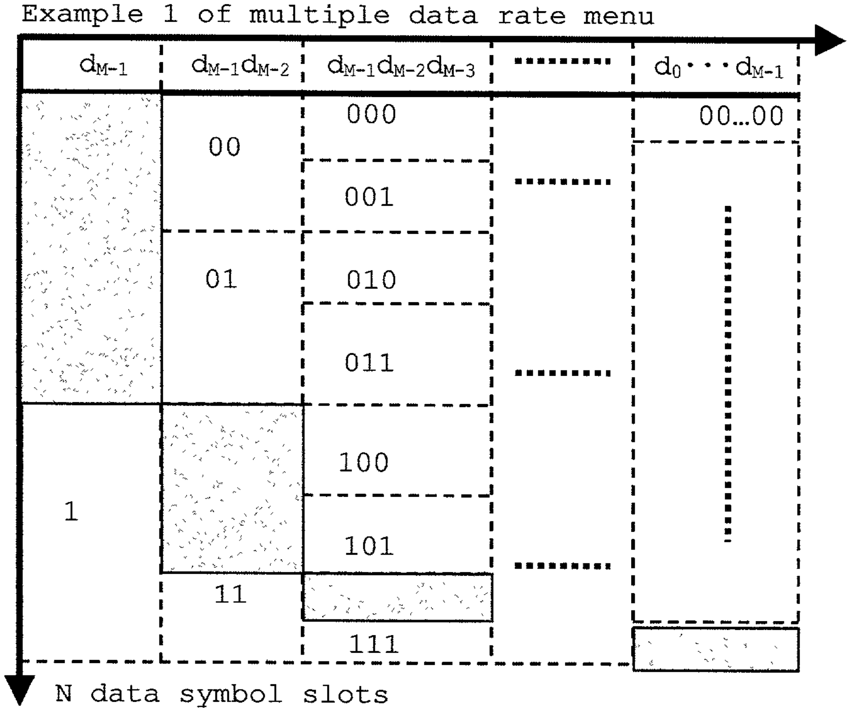
Menu of user assignments to the data vector fields

User group	Available channalization codes	Field assignment in data vector
u_0	$u_0=0$	$d_{M-1} \quad =0$
	$u_0=1$	$=1$
u_1	$u_1=0$	$d_{M-1}d_{M-2} \quad =00$
	$u_1=1$	$=01$
	$u_1=2$	$=10$
	$u_1=3$	$=11$
$\vdots$	$\vdots$	$\vdots$
u_{M-1}	$u_{M-1}=0$	$d_0 \cdots d_{M-1} = 00 \cdots 00$
	$\vdots$	$\vdots$
	$u_{M-1}=N-1$	$=11 \cdots 11$

39 Example 1 of multiple data rate menu:

There is 1 user for each group $u_0, u_1, \ldots, u_{M-2}$ and 2 users for u_{M-1} with each user selecting the lowest sequency channel corresponding to the lowest index of channels available to the group.

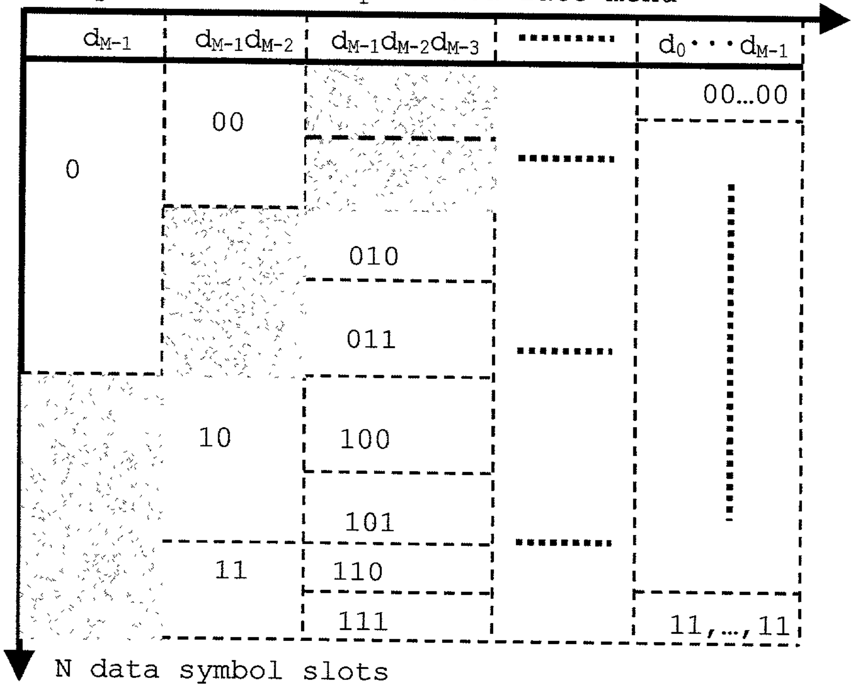
Example 1 of multiple data rate menu



40 Example 2 of multiple data rate menu:

There is 1 user in each group u_0 and $u_1$and 2 users in u_2 with each user selecting the highest sequency channel corresponding to the highest index of channels available to the group.

Example 2 of multiple data rate menu



41 Complex Walsh encoding and channel combining uses a computationally efficient fast encoding algorithm. This algorithm implements the encoding with an M pass computation. Passes 1,2,3,…,M respectively perform the 2,4,8,…,N chip complex Walsh encoding of the data symbol vector successively starting with the 2 chip encoding in pass 1, the 4 chip encoding in passes 1,2, the 8 chip encoding in pass 1,2,3, and the N chip encoding in passes 1,2,3,…,M where $N=2^M$. Using the binary word representations for both d and n, this M pass algorithm is:

Pass 1: $Z^{(1)}(n_{M-1}d_1 \cdots d_{M-1})$

$$= \sum_{d_0=dr_0=di_0=0,1} Z(d_0 \cdots d_{M-1})\left[(-1)\hat{}dr_0 n_{M-1} + j(-1)\hat{}di_0 n_{M-1}\right]$$

⋮

Pass m for m=2,…,M-1

$$Z^{(m)}(n_{M-1}\cdots n_{M-m}d_m\cdots d_{M-1})$$

$$= \sum_{d_{m-1}=dr_{m-1}=di_{m-1}=0,1} Z^{(m-1)}(n_{M-1}\cdots n_{M-m+1}d_{m-1}\cdots d_{M-1})\cdot [(1)\hat{\ }dr_{m-1}(n_{M-m}+n_{M-m+1})+j(-1)\hat{\ }di_{m-1}(n_{M-m}+n_{M-m+1}])$$

⋮

Pass M: $Z^{(M)}(n_{M-1}n_{M-2}\cdots n_1n_0)$

$$=\sum_{d_{M-1}=dr_{M-1}=di_{M-1}=0,1} Z^{(M-1)}(n_{M-1}n_{M-2}\cdots n_1d_{M-1})\cdot [(1)\hat{\ }dr_{M-1}(n_0+n_1)+j(-1)\hat{\ }di_{M-1}(n_0+n_1)]$$

$$= \tilde{Z}(n_{M-1}n_{M-2}\bullet\bullet\bullet n_1n_0)$$

An additional re-ordering pass is added to change the encoded N chip block $\tilde{Z}(n_{M-1}n_{M-2}\bullet\bullet\bullet n_1n_0)$ in bit reversed ordering to the normal readout ordering

$$\hat{Z}(n_0n_1\bullet\bullet\bullet n_{M-2}n_{M-1}) = \tilde{Z}(n)$$

42 PN scrambling

$P_R(n)$, $P_I(n)$ = PN code chip n for real and Imaginary axes

$Z(n)$ = PN scrambled complex Walsh encoded data chips after summing over the users

$$= \sum_u \tilde{Z}(n)\,[P_R(n)+j\,P_I(n)]$$

$$= \sum_u \tilde{Z}(n)\,[\mathrm{sgn}\{P_R(n)\}+j\,\mathrm{sgn}\{P_I(n)\}]$$

The fast algorithm in **41** is a computationally efficient means to implement the complex Walsh encoding of each N chip code block for multiple data rate users whose lowest data rate corresponds to the data symbol rate of an N chip encoded user. It is easily demonstrated that the number of real additions R_A per data symbol is approximately equal to $RA \approx 2M+2$ in the implementation of this fast algorithm **41**, where $N=2^M$. For the real Walsh encoding it is well known that the fast algorithm requires $R_A \approx M+1$ real additions per data symbol. Although the number of real adds has been doubled in using the complex Walsh compared to the real Walsh, the add operations are a low complexity implementation cost which means that the complex Walsh maintains its attractiveness as a zero-multiplication CDMA encoding orthogonal code set.

The fast algorithm in **41** consists of M signal processing passes on the stored data symbols to generate the complex Walsh CDMA encoded chips in bit reversed order. A re-ordering pass can changes the bit reversed output to the normal output. Advantage is taken of the equality c=d which allows the d to be used in the code indices for the complex Walsh: $d_m=c_m$, dr=cr, di=ci. Pass 1 implements 2 chip encoding, pass 2 implements 4 chip encoding, ….,and the last pass M performs $N=2^M$ chip encoding.

PN scrambling of the complex Walsh CDMA encoded chips in **42** is accomplished by encoding the $\{\tilde{Z}(n)\}$ with a complex PN which is constructed as the complex code sequence $[P_R(n)+jP_I(n)]$ wherein $P_R(n)$ and $P_I(n)$ are independent PN sequences used for the real and imaginary axes of the complex PN. These PN codes are 2-phase with each chip equal to +/-1 which means PN encoding consists of sign changes with each sign change corresponding to the sign of the PN chip. Encoding with PN means each chip of the summed complex Walsh encoded data symbols has a sign change when the corresponding PN chip is -1, and remains unchanged for +1 values. This operation is described by a multiplication of each chip of the summed complex Walsh encoded data symbols with the

sign of the PN chip. Purpose of the PN encoding for complex data symbols is to provide scrambling of the summed complex Walsh encoded data symbols as well as isolation between groups of users. Output of this complex Walsh CDMA encoding followed by the complex PN scrambling are the CDMA encoded chips over the N chip block $\{Z(n)\}$.

Transmitter equations (6) for hybrid complex Walsh orthogonal encoding of multiple data rate users are derived by starting with the hybrid complex Walsh orthogonal codes disclosed in the invention application [6]. The discrete Fourier transform (DFT) CDMA codes used in the example generation of hybrid complex Walsh orthogonal CDMA codes in [6] are given in equations (4) along with a fast encoding algorithm.

N-chip DFT complex orthogonal CDMA codes **(4)**

43 DFT code vectors

E_N = DFT NxN orthogonal code matrix consisting of N rows of N chip code vectors

= $[\ E_N(c)\ ]$ matrix of row vectors $E(c)$

= $[E_N\ (c,n)\ ]$ matrix of elements $E(c,n)$

$E_N\ (c)$ = DFT code vector c

= $[E_N\ (c,0),\ E_N\ (c,1),\ \ldots,\ E_N\ (c,N-1)\ ]$

= 1xN row vector of chips $E_N\ (c,0),\ldots,\ E_N\ (c,N-1)$

$E_N\ (c,n)$ = DFT code c chip n

$= e^{j2\pi\, cn/N}$

$= \cos(\ 2\pi\ cn/N) + j\sin(\ 2\pi\ cn/N)$

= N possible values on the unit circle

44 Fast encoding algorithm for N chip block of data in the data vector $d=d_0d_1\cdots d_{M-2}\ d_{M-1}$

Pass 1: $Z^{(1)}(d_0d_1\cdots d_{M-2}\ n_0)$

$$= \sum_{d_{M-1}=0,1} Z(d_0d_1d_2\cdots d_{M-2}d_{M-1})\,(e^{j2\pi})\text{^}d_{M-1}n_0/2$$

⋮

Pass m for m=2,…,M-1

$$Z^{(m)}(d_0\cdots d_{M-m-1}n_{m-1}\cdots n_0)$$
$$= \sum_{d_{M-m}} Z^{(m-1)}(d_0\cdots d_{M-m}n_{m-2}\cdots n_0)\bullet e\hat{\ }j2\pi[d_{M-m}(n_0+n_1 2+\cdots+n_{m-1}2\hat{\ }(m-1))/2^m]$$

⋮

Pass M for m=2,…,M-1

$$Z^{(M)}(n_{M-1}\cdots n_0)$$
$$= \sum_{d_0} Z^{(m-1)}(d_0 n_{M-2}\cdots n_0)\bullet e\hat{\ }j2\pi[d_0(n_0+n_1 2+\cdots+n_{M-1}2\hat{\ }(M-1))/2^M]$$
$$= \tilde{Z}(n_{M-1}n_{M-2}\cdots n_1 n_0)$$

An additional re-ordering pass is added to change the encoded N chip block $\tilde{Z}(n_{M-1}n_{M-2}\bullet\bullet\bullet n_1 n_0)$ in bit reversed ordering to the normal readout ordering

$$\tilde{Z}(n_0 n_1 \bullet\bullet\bullet n_{M-2}n_{M-1}) = \tilde{Z}(n)$$

An additional re-ordering pass is added to change the encoded N chip block $\tilde{Z}(n_{M-1}n_{M-2}\bullet\bullet\bullet n_1 n_0)$ in bit reversed ordering to the normal readout ordering

$$\tilde{Z}(n_0 n_1 \bullet\bullet\bullet n_{M-2}n_{M-1}) = \tilde{Z}(n)$$

DFT code matrix and the row code vectors are defined in **43** for an N chip block. A fast algorithm for the encoding of the N chip data vector $Z(d_0 d_1 d_2\cdots d_{M-2}d_{M-1})$ is defined in **44** in a format similar to the fast algorithm for the complex Walsh encoding in equations (3). It is well known that the computational complexity of the fast DFT encoding algorithm is $R_A \approx 2M$ real

additions per data symbol plus $R_M \approx 3M$ real multiplications per data symbol. The relatively high complexity implementation cost of multiplies makes it desirable to limit the use of DFT codes to applications such as the hybrid complex Walsh wherein the number of real multiplies per data symbol can be kept more reasonable.

Hybrid complex Walsh orthogonal CDMA codes increase the flexibility in choosing the code lengths for multiple data rate users at the implementation cost of introducing multiply operations into the CDMA encoding and decoding. Two of several means for construction given in the patent application [6] are the Kronecker product and the direct sum. The direct sum will not be considered since the addition of the zero matrix in the construction is generally not desirable for CDMA communications although the direct sum construction provides greater flexibility in the choice of N without necessarily introducing a multiply penality. Using the Kronecker product construction in reference [6] the hybrid complex Walsh orthogonal CDMA codes can be constructed as demonstrated in equations (4).

Equations (5) list construction and examples of the hybrid complex Walsh orthogonal CDMA codes using the Kronecker approach and DFT matrices E_N to expand the complex Walsh to a hybrid complex Walsh. Low order CDMA code examples **45** illustrate fundamental relationships between the DFT, complex Walsh, and the real Walsh or equivalently Hadamard. Kronecker construction is defined in **46.** CDMA current and developing standards use the prime 2 which generates a code length $N=2^M$ where M=integer. For applications requiring greater flexibility in code length N, additional primes can used using the Kronecker construction. We illustrate this in the examples **47** with the addition of prime=3. The use of prime=3 in addition to the prime=2 in the range of N=8 to 64 is observed to increase the number of N choices from 4 to 9 at a modest cost penality of using multiples of the angle increment 30 degrees for prime=3 in addition to the angle increment 90 degrees for prime=2. As noted in **46** there

are several choices in the ordering of the Kronecker product construction and 2 of these choices are used in the construction.

Examples of hybrid complex Walsh orthogonal codes (5)

45 Examples of low-order codes

$$2\text{x}2 \quad E_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$= (e^{-j\pi/4}/\sqrt{2}) * \widetilde{W}_2$$

$$= H_2 \quad \text{2x2 Hadamard}$$

$$3\text{x}3 \quad E_3 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j2\pi/3} & e^{j2\pi 2/3} \\ 1 & e^{j2\pi 2/3} & e^{j2\pi/3} \end{bmatrix}$$

$$4\text{x}4 \quad \widetilde{W}_4 = \begin{bmatrix} 1+j & 1+j & 1+j & 1+j \\ 1+j & -1+j & -1-j & 1-j \\ 1+j & -1-j & 1+j & -1-j \\ 1+j & 1-j & -1-j & -1+j \end{bmatrix}$$

$$E_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

$$= (e^{-j\pi/4}/\sqrt{2}) \ \widetilde{W}_4$$

46 Kronecker product construction for $N = \prod_k N_k$

Code matrix C_N = NxN hybrid orthogonal CDMA code matrix

Kronecker product construction of C_N

$$C_N = C_0 \prod_{k>0} \otimes C_{N_k}$$

Kronecker product definition

A = $N_a x N_a$ orthogonal code matrix

B = $N_b x N_b$orthogonal code matrix

$A \otimes B$ = Kronecker product of matrix A and matrix B

= $N_a N_b$ x $N_a N_b$ orthogonal code matrix consisting of the elements $[a_{ik}]$ of matrix A multiplied by the matrix B

= $[\ a_{ik}\ B\ ]$

47 Kronecker product construction examples for primes p=2,3 and the range of sizes $8 \leq N \leq 64$

8x8	C_8	=	$\widetilde{W}_8$
12x12	C_{12}	=	$\widetilde{W}_4 \otimes E_3$
	C_{12}	=	$E_3 \otimes \widetilde{W}_4$
16x16	C_{16}	=	$\widetilde{W}_{16}$
18x18	C_{18}	=	$\widetilde{W}_2 \otimes E_3 \otimes E_3$
	C_{18}	=	$E_3 \otimes E_3 \otimes \widetilde{W}_2$
24x24	C_{24}	=	$\widetilde{W}_8 \otimes E_3$
	C_{24}	=	$E_3 \otimes \widetilde{W}_8$
32x32	C_{32}	=	$\widetilde{W}_{32}$
36x36	C_{36}	=	$\widetilde{W}_4 \otimes \widetilde{W}_3 \otimes \widetilde{W}_3$
	C_{36}	=	$\widetilde{W}_3 \otimes \widetilde{W}_3 \otimes \widetilde{W}_4$
48x48	C_{48}	=	$\widetilde{W}_{16} \otimes \widetilde{W}_3$
	C_{48}	=	$\widetilde{W}_3 \otimes \widetilde{W}_{16}$
64x64	C_{64}	=	$\widetilde{W}_{64}$

A fast algorithm for the encoding of the hybrid complex Walsh CDMA orthogonal codes is described in equations (6) for the representative example **48** which constructs the NxN hybrid complex Walsh orthogonal CDMA code matrix $C_N = \widetilde{W}_{N_0} \otimes E_{N_1}$ as the

Kronecker product of the $N_0 x N_0$ complex Walsh $\widetilde{W}_{N_0}$ and the $N_1 x N_1$ complex DFT, where $N=N_0N_1$. Each chip element of C_N is the product **49** of the chip elements of the complex Walsh and complex DFT code matrices. The complex Walsh and DFT codes are phase codes which means the phase of each C_N chip element is the sum of the phases of the chip elements for the complex Walsh and complex DFT. Chip element equations are $C_N(c,n) = \widetilde{W}_{N_0}(c\widetilde{w}, n\widetilde{w})\, E_{N_1}(ce,ne)$ with $c = ce + c\widetilde{w} N_1$ and $n = ne + n\widetilde{w} N_1$. For multiple data rate data symbol assignments and for the construction of the fast encoding algorithm, it is convenient to use a binary word representation of the chip element indices c,n. Binary word representation **50** is $c = ce_0 ce_1 \cdots ce_{M_1-1} c\widetilde{w}_{M_1} c\widetilde{w}_{M_1+1} \cdots c\widetilde{w}_{M-1} = c_0 c_1 \cdots c_{M-2} c_{M-1}$ where the first binary word is a function of the binary words for the complex Walsh and complex DFT code indices, and the second binary word is a direct representation of the C_N indices which will be used for the data vector construction. The same binary word representations apply for the chip index n upon substituting the n for c. User data **38** in equations (3) for the N chip code block is mapped into the N data symbol vector $d= d_0 \cdots d_{M-1}$ which is obtained from the binary word for c by substituting the index d for the index c in the binary word representation.

The multiple data rate data symbol mapping **51** in equations (6) for the hybrid complex Walsh codes remains the same as used in **38**, **39**, **40** in equations (3) for the complex Walsh codes. The data symbol mapping assigns the N/2 data symbols of the 2 chip data symbol transmission rate users to the d_{M-1} field, the N/4 data symbols of the 4 chip data symbol transmission rate users are assigned to the $d_{M-1}d_{M-2}$ field, …., and the single data symbols of the N chip data symbol transmission rate users are assigned to the $d_0 \cdots d_{M-1}$ field, where the data vector index "d" is represented as the binary number $d=d_0 \cdots d_{M-1}$ and the $\{d_m\}$ are the binary coefficients. For a fully loaded CDMA communications

frequency band the N data symbols occupy the N available data symbol locations in the data symbol vector $d = d_0 \cdots d_{M-1}$. The menu of available user assignments to the data vector fields is given in **38** in equations (3). Examples 1 and 2 in **39** and **40** in equations (3) illustrate representative user assignments to the data fields of the data symbol vector. This mapping of the user data symbols into the data symbol vector is equivalent to setting c=d which makes it possible to develop the fast encoding algorithm **51**.

Fast multiple data rate hybrid complex Walsh encoding for transmitter **(6)**

48 The fast algorithm will be described for the example NxN complex orthogonal CDMA code matrix C_N which is generated by the Kronecker product of the $N_0 x N_0$ complex Walsh matrix $\widetilde{W}_{N_0}$ and the complex $N_1 x N_1$ DFT matrix E_{N_1}

C_N = Kronecker product of $\widetilde{W}_{N_0}$ and E_{N_1}

$$= \widetilde{W}_{N_0} \otimes E_{N_1}$$

where $N = N_0 N_1$

$= 2^M$

$M = M_0 + M_1$

$N_0 = 2^{M_0}$

$N_1 = 2^{N_1}$

49 N chip hybrid complex Walsh code block C_N

C_N = hybrid complex Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= $[C_N(c)]$ matrix of row vectors $C_N(c)$

= $[C_N(c,n)]$ matrix of elements $C_N(c,n)$

$C_N(c,n)$ = hybrid complex Walsh code c chip n

$$= \widetilde{W}_{N_0}(c\widetilde{w}, n\widetilde{w})\, E_{N_1}(ce, ne)$$

$$= [+/-1 \; +/-j] \; E_{N_1}(ce, ne) \quad \text{values}$$

where $c = ce + c\widetilde{w} N_1$

$n = ne + n\widetilde{w} N_1$

50 Binary indexing of codes in the matrix C_N

$$
\begin{aligned}
c &= ce_0 + ce_1 2 + \cdots + ce_{M_1-1} 2^\wedge(M_1 - 1) \\
&\quad + c\tilde{w}_{M_1} 2^\wedge M_1 + c\tilde{w}_{M_1+1} 2^\wedge(M_1+1) + \cdots + c\tilde{w}_{M-1} 2^\wedge M - 1 \\
&= ce_0 ce_1 \cdots ce_{M_1-1} c\tilde{w}_{M_1} c\tilde{w}_{M_1+1} \cdots c\tilde{w}_{M-1} \qquad \text{Binary word} \\
n &= ne_0 + ne_1 2 + \cdots + ne_{M_1-1} 2^\wedge(M_1 - 1) \\
&\quad + n\tilde{w}_{M_1} 2^\wedge M_1 + n\tilde{w}_{M_1+1} 2^\wedge(M_1+1) + \cdots + n\tilde{w}_{M-1} 2^\wedge M - 1 \\
&= ne_0 ne_1 \cdots ne_{M_1-1} n\tilde{w}_{M_1} n\tilde{w}_{M_1+1} \cdots n\tilde{w}_{M-1} \qquad \text{Binary word}
\end{aligned}
$$

51 The fast encoding algorithm starts with the data symbol vector d and mapping of the user groups u_0, u_1, …., u_{M-1} into the data fields of d. This mapping is identical to the mapping defined in equations (3) for the multiple data rate complex Walsh orthogonal encoding of the CDMA over an N chip block. However, the fast algorithm for the hybrid complex Walsh encoding is modified to accommodate the Kronecker construction as illustrated by the following fast algorithm for the hybrid complex Walsh example in **48**. Using the binary representations of d,n

$$
\begin{aligned}
d &= d_0 d_1 \cdots\cdots d_{M_1-1} d_{M_1} \cdots\cdots d_{M-1} \\
&= de_0 de_1 \cdots de_{M_1-1} d\tilde{w}_{M_1} \cdots d\tilde{w}_{M-1} \\
n &= n_0 n_1 \cdots\cdots n_{M_1-1} n_{M_1} \cdots\cdots n_{M-1} \\
&= ne_0 ne_1 \cdots ne_{M_1-1} n\tilde{w}_{M_1} \cdots n\tilde{w}_{M-1}
\end{aligned}
$$

and the same approach used to derive the fast algorithms **41** in equations (3) and **44** in equations (4), enables the M pass fast algorithm to be defined

Pass 1 for complex Walsh codes

$$
Z^{(1)}(d_0 \cdots d_{M_1-1}\, n_{M1}\, d_{M_1+1} \cdots d_{M-1})
$$

$$
= \Sigma\ Z(d_0 \cdots d_{M-1}) \cdot
$$

$$[(-1)^\wedge dr_{M_1} n_{M_1} + j(-1)^\wedge \; di_{M_1} n_{M_1} +]$$

$$d_{M_1} = dr_{M_1} = di_{M_1} = 0,1$$

Pass m for m=2,…,M_0 for complex Walsh codes

$$Z^{(m)}(d_0 \cdots d_{M_1-1} n_{M_0-1} \cdots n_{M_0-m} d_{M_1+m} \cdots d_{M-1})$$

$$= \sum Z^{(m-1)}(d_0 \cdots d_{M_1-1} n_{M_0-1} \cdots n_{M_0-m+1} d_{M_1+m-1} \cdots d_{M-1}) \cdot$$

$$[(-1)^\wedge dr_{m-1}(n_{M_0-m} + n_{M_0-m+1}) +$$

$$+ j(-1)^\wedge di_{m-1}(n_{M_0-m} + n_{M_0-m+1})]$$

$$d_{M_1+m-1} = dr_{m-1} = di_{m-1} = 0,1$$

⋮

Pass $M_0+m=M_0+1,\ldots,M_0+M_1-1=M-1$ for complex DFT codes

$$Z^{(M_0+m)}(d_0 \cdots d_{M_1-m-1} n_{M_0+m-1} \cdots n_0)$$

$$= \sum Z^{(M_0+m-1)}(d_0 \cdots d_{M_1-m} n_{M_0+m-2} \cdots n_0) \bullet$$

$$[e^\wedge j2\pi)^\wedge d_{M_1-m}(n_{M_0} + n_{M_0+1} 2 + \cdots + n_{M_0+m-1} 2^\wedge m-1)/2^\wedge m]$$

$$d_{M_1-m} = 0,1$$

⋮

Pass M for complex DFT codes

$$Z^{(M)}(n_{M-1} \cdots n_1 n_0)$$

$$= \sum Z^{(M-1)}(d_0 n_{M-2} \cdots n_1 n_0) \bullet$$

$$[e\wedge j2\pi)\wedge d_0(n_{M_0} + n_{M_0+1}2 + \cdots + n_{M-1}2\wedge M_0 - 1)/2\wedge M_0]$$

$d_0=0,1$

$= \tilde{Z}\,(n_{M-1}n_{M-2}\cdots n_1n_0)$

An additional re-ordering pass is added to change the encoded N chip block $\tilde{Z}\,(n_{M-1}n_{M-2}\bullet\bullet\bullet n_1n_0)$ in bit reversed ordering to the normal readout ordering

$$\hat{Z}(n_0n_1 \bullet\bullet\bullet n_{M-2}n_{M-1}) = \tilde{Z}(n)$$

The fast algorithm in **51** is a computationally efficient means to implement the hybrid complex Walsh encoding of each N chip code block for multiple data rate users whose lowest data rate corresponds to the data symbol rate of an N chip encoded user. The computational complexity of this fast encoding algorithm can be estimated using the computational complexities of the complex Walsh and the DFT fast encoding algorithms, which gives the estimate: $R_A \approx 2M+M_1+2$ real additions per data symbol, and $R_M \approx 2M_1$ real multiplies per data symbol.

The fast algorithm in **51** consists of M signal processing passes on the stored data symbols, followed by a re-ordering pass for readout of the N chip block of encoded data symbols. Advantage is taken of the equality c=d which allows the d to be used in the code indices for the complex Walsh: $d_m=c_m$, dr=cr, di=ci. Pass 1 implements 2 chip encoding, passes $m=2,\ldots,M_0$ implement 2^m chip encoding with the complex Walsh codes, passes $M_0+1, M_0+2, \ldots, M_0+M_1-1=M-1$ implement $2\wedge M_0+m$ chip encoding with the complex DFT codes, and the last pass M encodes the $N=2^M$ chip data symbols with the DFT codes. This fast algorithm only differs from the fast algorithm in **46** in equations (4) in the use of both the complex Walsh codes and the complex DFT codes with their Kronecker indexing. Unlike the fast algorithm for the real Walsh encoding as well as the algorithm for the complex DFT encoding,

the complex Walsh portion of the fast algorithm **51** uses both the sign of the complex Walsh code from the current pass and from the previous pass starting with pass 2.

The generalization of the fast algorithm in **51** in equations (6) to other Kronecker product constructions for C_N and to the more general constructions for C_N discussed in reference [6} should be apparent to anyone skilled in the CDMA communications art.

Receiver equations (7) describe a representative multiple data rate complex Walsh CDMA decoding for multiple data users for the receiver in FIG. 3 using the definition of the complex Walsh CDMA codes in the invention application [6]. The receiver front end **52** provides estimates $\{\hat{Z}(n)\}$ of the transmitted multiple data rate complex Walsh CDMA encoded chips {Z(n)}. Orthogonality property **53** is expressed as a matrix product of the complex Walsh code chips or equivalently as a matrix product of the complex Walsh code chip numerical signs of the real and imaginary components, for any of the 2,4,8,…,N/2,N chip complex Walsh channelization codes and their repetitions over the N chip code block. The 2-phase PN codes **54** have the useful decoding property that the square of each code chip is unity which is equivalent to observing that the square of each code chip numerical sign is unity.

Receiver decoding of complex Walsh and hybrid complex Walsh CDMA encoded chips **(7)**

52 Receiver front end in FIG. 3 provides estimates

$\{\hat{Z}(n)\}$ **28** of the encoded transmitter chip symbols

{Z(n)} **41** in equations (3)

53 Orthogonality properties of the complex Walsh NxN matrix

$$\sum_n \widetilde{W}_N(\hat{c},n)\,\widetilde{W}_N^{\,*}(n,c) \;=$$

$$\sum_n [\,\mathrm{sgn}\{W_N(\hat{c}r,n) + j\,\mathrm{sgn}\{W_N(\hat{c}i,n)\}\,][\,\mathrm{sgn}\{W_N(n,cr)\} - j\,\mathrm{sgn}\{W_N(n,ci)\}\,]$$

$$= 2N\ \delta(\hat{c}, c)$$

where $\hat{c}, c, n = 0, 1, \ldots, N$

$\delta(\hat{c}, c)$ = Delta function of $\hat{c}$ and c

= 1 for $\hat{c} = c$

= 0 otherwise

cr=cr(c), ci=ci(c) are defined in equations (3)

54 PN de-scrambling of the receiver estimates of the complex and hybrid complex Walsh encoded data chips

$P_R(n), P_I(n)$ = PN code chip n for real and imaginary axes

$\tilde{\hat{Z}}(n)$ = PN de-scrambled receiver estimates of the transmitted CDMA encoded chips $\hat{Z}(n)$

$$= \hat{Z}(n)\ [P_R(n) - j\,P_I(n)]$$

55a Complex Walsh decoding and uses a computationally efficient fast encoding algorithm. This algorithm implements the decoding with an M pass computation. Passes 1,2,3,…,M respectively perform the 2,4,8,…,N chip complex Walsh decoding of the data symbol vector successively starting with the 2 chip decoding in pass 1, the 4 chip decoding in passes 1,2, and the N chip decoding in passes 1,2,3,…,M where $N=2^M$. Using the binary word representations for both d and n, this M pass algorithm is:

Pass 1:

$$\hat{Z}^{(1)}(d_{M-1} n_1 n_2 \cdots n_{M-2}\ n_{M-1})$$

$$= \sum_{n_0=0,1} \tilde{\hat{Z}}(n_0 n_1 n_2 \cdots n_{M-2} n_{M-1}) \bullet [(-1)^{\wedge}\ n_0 dr_{M-1} - j(-1)^{\wedge}\ n_0 di_{M-1}]$$

Pass m for m=2,…,M-1

$$\hat{Z}^{(m)}(d_{M-1}d_{M-2}\cdots d_{M-m}n_m\cdots n_{M-2}n_{M-1})$$

$$=\sum_{n_{m-1}=0,1}\hat{Z}^{(m-1)}(d_{M-1}d_{M-2}\cdots d_{M-m+1}n_{m-1}\cdots n_{M-2}n_{M-1})\cdot$$
$$[(-1)\hat{\ }n_{m-1}(dr_{M-m}+dr_{M-m+1})-j(-1)\hat{\ }n_{m-1}(di_{M-m}+di_{M-m+1})]$$

$\vdots$

Pass M

$$\hat{Z}^{(M)}(d_{m-1}d_{m-2}\cdots d_0)$$

$$=\sum_{n_{M-1}=0,1}\hat{Z}^{(M-1)}(d_{M-1}d_{M-2}\cdots d_1n_0)\cdot$$
$$[(-1)\hat{\ }n_{M-1}(dr_0+dr_1)\ -j(-1)\hat{\ }n_{M-1}(di_0+di_1)]$$

$$=N\hat{Z}(d_{m-1}d_{m-2}\cdots d_0)$$

An additional re-ordering pass is added to change the decoded N chip block $\hat{Z}(d_{m-1}d_{m-2}\cdots d_0)$ in bit reversed ordering to the normal readout ordering. In this representative fast implementation the scaling factor N has been removed in the re-ordering pass whereas a typical implementation will re-scale each pass. The output of this final pass is the receiver estimate of the transmitted data symbol vector

$$\hat{Z}(d_0d_2\cdots d_{M-1})=\hat{Z}(d)$$

55b Hybrid complex Walsh decoding uses a computationally efficient fast encoding algorithm. Similar to the complex Walsh this algorithm implements the decoding with an M pass computation 1,2,3,…,M:

1315 Pass m= 1,…,M1 for complex DFT codes

$$\hat{Z}^{(m)}(n_0 \cdots n_{M-m-1} d_{m-1} \cdots d_0)$$

$$= \Sigma \ \hat{Z}^{(m-1)}(n_0 \cdots n_{M-m}\, \mathrm{d}_{\mathrm{m-2}} \cdots \mathrm{d}_0) \bullet$$

$$[\, e \wedge j2\pi) \wedge n_{M-m}(d_0 + d_1 2 + \cdots + d_{m-1} 2 \wedge m-1)/2 \wedge m \,]$$

1320 $\mathrm{n}_{\mathrm{M}-m}$=0,1

1325 Pass M1+m=M1+1,M1+2,….,M-1 for complex Walsh codes

$$\hat{Z}^{(M_1+m)}(\mathrm{d}_{\mathrm{M-1}} \cdots \mathrm{d}_{\mathrm{M-m}}\, n_m \cdots n_{M_0-1} \mathrm{d}_{\mathrm{M_1-1}} \cdots d_0)$$

$$= \Sigma \ \hat{Z}^{(M_1+m-1)}(\mathrm{d}_{\mathrm{M-1}} \cdots \mathrm{d}_{\mathrm{M-m-1}}\, n_{m-1} \cdots n_{M_0-1} \mathrm{d}_{\mathrm{M_1-1}} \cdots d_0) \bullet$$

$$[\,(-1) \wedge n_{m-1}(dr_{M_0-m} + dr_{M_0-m+1})$$

$$-j\,(-1) \wedge n_{m-1}(di_{M_0-m} + di_{M_0-m+1})$$

1330

n_{m-1}=0,1

1335

Pass M for complex Walsh codes

$$\hat{Z}^{(M)}(d_{M-1}\cdots d_1 d_0)$$

$$= \sum_{n_{M_0-1}=0,1} \hat{Z}^{(M-1)}(d_{M-1}\cdots d_{M-m-1}\, n_{M_0-1}\, d_{M_1-1}\cdots d_0)\bullet$$

$$[(-1)\wedge n_{M_0-1}(dr_0+dr_1)$$

$$-j(-1)\wedge n_{M_0-1}(di_0+di_1)$$

$$= \hat{Z}(d_{M-1}d_{M-2}\cdots d_1 d_0)$$

An additional re-ordering pass is added to change the decoded N chip block $\hat{Z}(d_{m-1}d_{m-2}\cdots d_0)$ in bit reversed ordering to the normal readout ordering. In this representative fast implementation the scaling factor N has been removed in the re-ordering pass whereas a typical implementation will re-scale each pass. The output of this final pass is the receiver estimate of the transmitted data symbol vector

$$\hat{Z}(d_0 d_2\cdots d_{M-1}) = \hat{Z}(d)$$

The fast decoding algorithms **55a, 55b** perform the inverse of the signal processing for the encoding **41, 51** in equations (3),(6) of the complex, hybrid complex Walsh respectively, to recover estimates $\{\hat{Z}(d)\}$ of the transmitter user data symbols $\{Z(d)\}$. These algorithms are computationally efficient means to implement the complex and hybrid complex Walsh decoding of each N chip code block for multiple data rate users whose lowest data rate corresponds to the data symbol rate of an N chip encoded

user. For the fast complex Walsh decoding algorithm in **55a** the number of required real additions R_A per data symbol is approximately equal to $RA \approx 2M+2$ which is identical to the complexity metric for the fast encoding algorithm. For the fast hybrid complex Walsh decoding algorithm in **55b** the computational complexity is $R_A \approx 2M+M_1+2$ real additions per data symbol and $R_M \approx 2M_1$ real multiplies per data symbol which is identical to the complexity metric for the fast encoding algorithm.

For the complex Walsh decoding the fast algorithm **55a** implements M signal processing passes on the N chip block of received data chips after de-scrambling, followed by a re-ordering pass of the receiver recovered estimates of the data symbols. Passes m=1,2,....,M implement 2^m chip decoding. For the hybrid complex Walsh the fast algorithm **55b** combines the complex Walsh algorithm with a DFT algorithm in M signal processing passes where $M=M_0+M_1$ with M_0, M_1 respectively designating the complex Walsh, DFT decoding passes. Passes $m=1,\ldots,M_1$ implement the complex DFT decoding and the remaining passes $M_1+1,\ldots, M-1$ implement decoding with the complex Walsh codes, and the last pass M completes the complex decoding.

FIG. 5 complex/hybrid complex Walsh CDMA encoding is a representative implementation of the complex and hybrid complex (complex/hybrid complex) Walsh CDMA encoding which replaces the current real Walsh encoding **13** in FIG. 1, and is defined in equations (3) and (6). The input user data symbols $\{Z(u_{m,k_m})\}$ **56** are mapped into the data symbol vector **57** Z(d) as described in equations (3). Data symbols {Z(d)} are encoded and summed over the user data symbols in **58** and **59** by the fast encoding algorithm in equations **41** in (3) for the complex Walsh and in equations **51** in (6) for the hybrid complex Walsh. For the hybrid complex Walsh, the fast complex DFT encoding **59** follows the fast complex Walsh encoding **58.** This encoding and summing over the user data symbols is followed by PN encoding with the

scrambling sequence $[P_R(n)+jP_I(n)]$ **60**. Output is the stream of complex CDMA encoded chips {Z(n)} **61.**

It should be obvious to anyone skilled in the communications art that this example implementation in FIG. 5 clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

FIG. 6 complex/hybrid complex Walsh CDMA decoding is a representative implementation of complex/hybrid Walsh CDMA decoding which replaces the current real Walsh decoding **27** in FIG. 3 and is defined in equations (7). Inputs are the received estimates of the complex CDMA encoded chips $\{\hat{Z}(n)\}$ **62.** The PN scrambling code is stripped off from these chips **63** by changing the sign of each chip according to the numerical sign of the real and imaginary components of the complex conjugate of the PN code as per the decoding algorithms **54** in equations (7).The complex/hybrid complex Walsh channelization coding is removed by the fast decoding algorithms in equations **55** in (7) for the complex/hybrid complex Walsh, to recover the receiver estimates $\{\hat{Z}(d)\}$ of the transmitted data symbols {Z(d)}. The complex Walsh fast decoding **64** is followed by the complex DFT fast decoding **65** for the hybrid complex Walsh. Decoded outputs are the estimated data vector $\hat{Z}(d)$ **66** whose entries are read out as the set of receiver estimates $\{\hat{Z}(u_{m,k_m})\}$ **67** of the transmitted data symbols.

It should be obvious to anyone skilled in the communications art that this example implementation in FIG. 6 clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

Preferred embodiments in the previous description is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is not to be accorded the wider scope consistent with the principles and novel features disclosed herein.

It should be obvious to anyone skilled in the communications art that this example implementation of the complex Walsh and hybrid complex Walsh for multiple data rate users in equations (3),…,(7) clearly defines the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches. For example, the Kronecker matrices E_N and H_N can be replaced by functionals.

For cellular applications the transmitter description which includes equations (18) describes the transmission signal processing applicable to this invention for both the hub and user terminals, and the receiver corresponding to the decoding of equations (18) describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.

For optical communications applications the the microwave processing at the front end of both the transmitter and the receiver is replaced by the optical processing which performs the complex modulation for the optical laser transmission in the transmitter and which performs the optical laser receiving function of the microwave processing to recover the complex baseband received signal.